



Recent Charm Physics Results From CDF

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Meeting of DPF
The Division of Particles and Fields
OF THE AMERICAN PHYSICAL SOCIETY

2004

CR



Outline

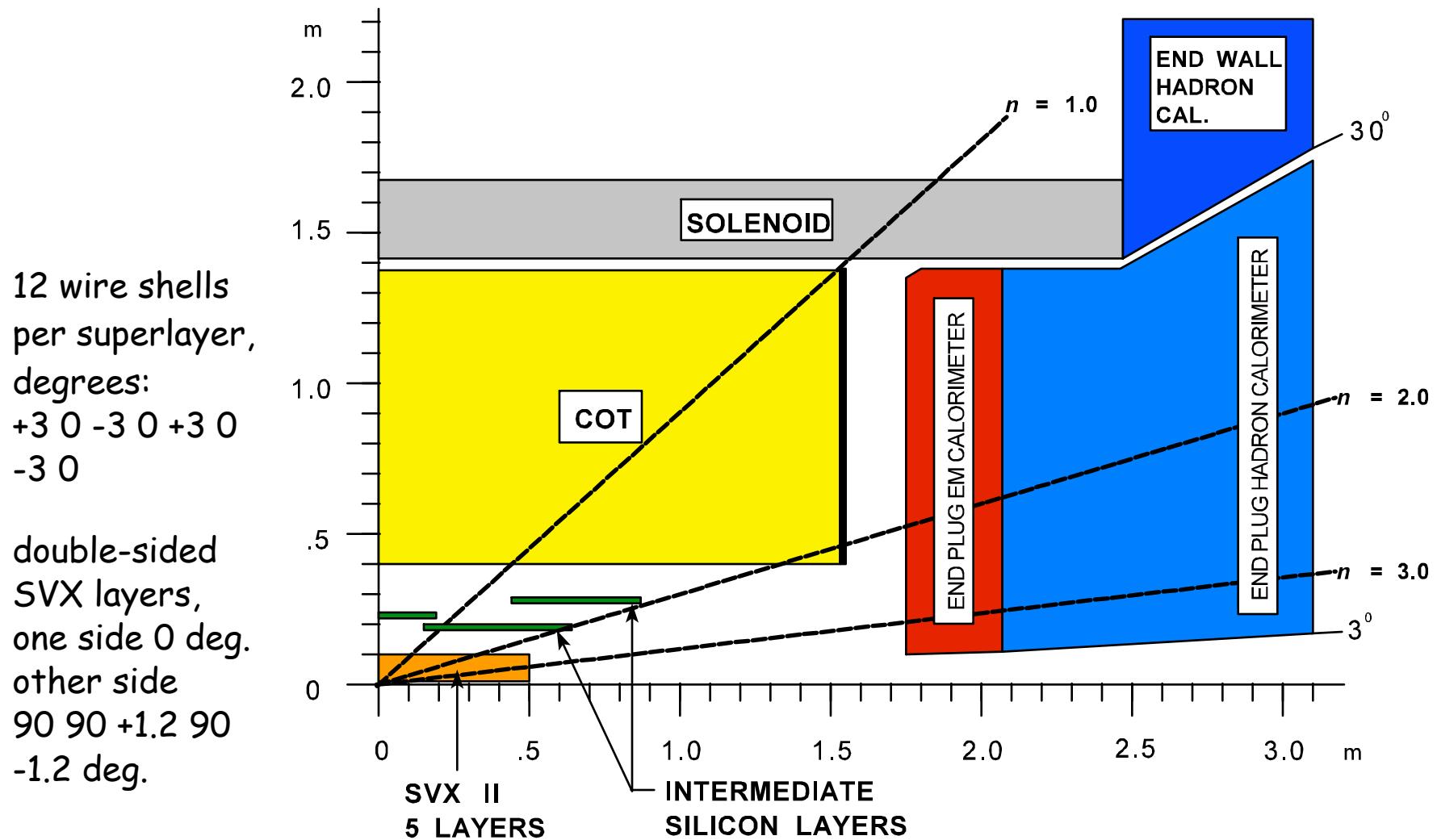
Triggering for Charm

Mass and Width of the Narrow Width $L = 1 D^{**}$ Mesons

Relative Branching Fraction and Search for Direct CP Asymmetry in
 $D^0 \rightarrow K^+ K^-$ and $\pi^+ \pi^-$ decays

Prospect of Search for Direct CP Asymmetry in $D^+ \rightarrow \pi^+ \pi^- \pi^+$ decays

CDF Tracking Volume



CDF Trigger System

level	rate	latency
Bunch crossing	2.5 MHz	
Level 1	30 KHz	5.5 μ sec
Level 2	400 Hz	20 μ sec

Level 1 - eXtremely Fast Tracker (XFT)

$P_{\tau 1} > 2 \text{ GeV}/c$ and $P_{\tau 2} > 2 \text{ GeV}/c$

$P_{\tau 1} + P_{\tau 2} > 5.5 \text{ GeV}/c$

Level 2 - Silicon Vertex Tracker (SVT) - two track trigger

each track impact parameter between 120 μm and 1000 μm

secondary vertex with transverse decay length $L_{xy} > 200 \mu\text{m}$

Level 3 - Full Event Reconstruction

8/30/2004

confirm L2

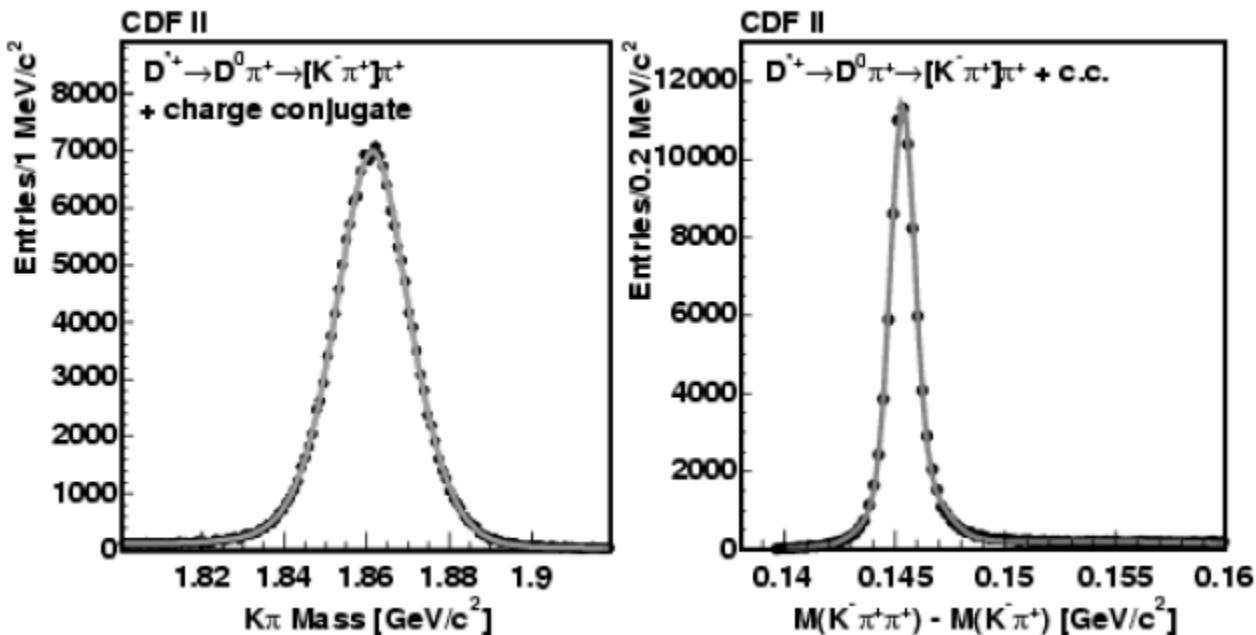
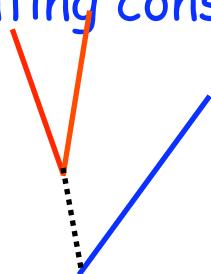
P. Karchin, Charm Physics @ CDF, DPF@UCR

$$D^{*+} \rightarrow D^0 \pi^+, D^0 \rightarrow K^- \pi^+ + c.c.$$

180910 ± 480 Signal 123 pb^{-1}

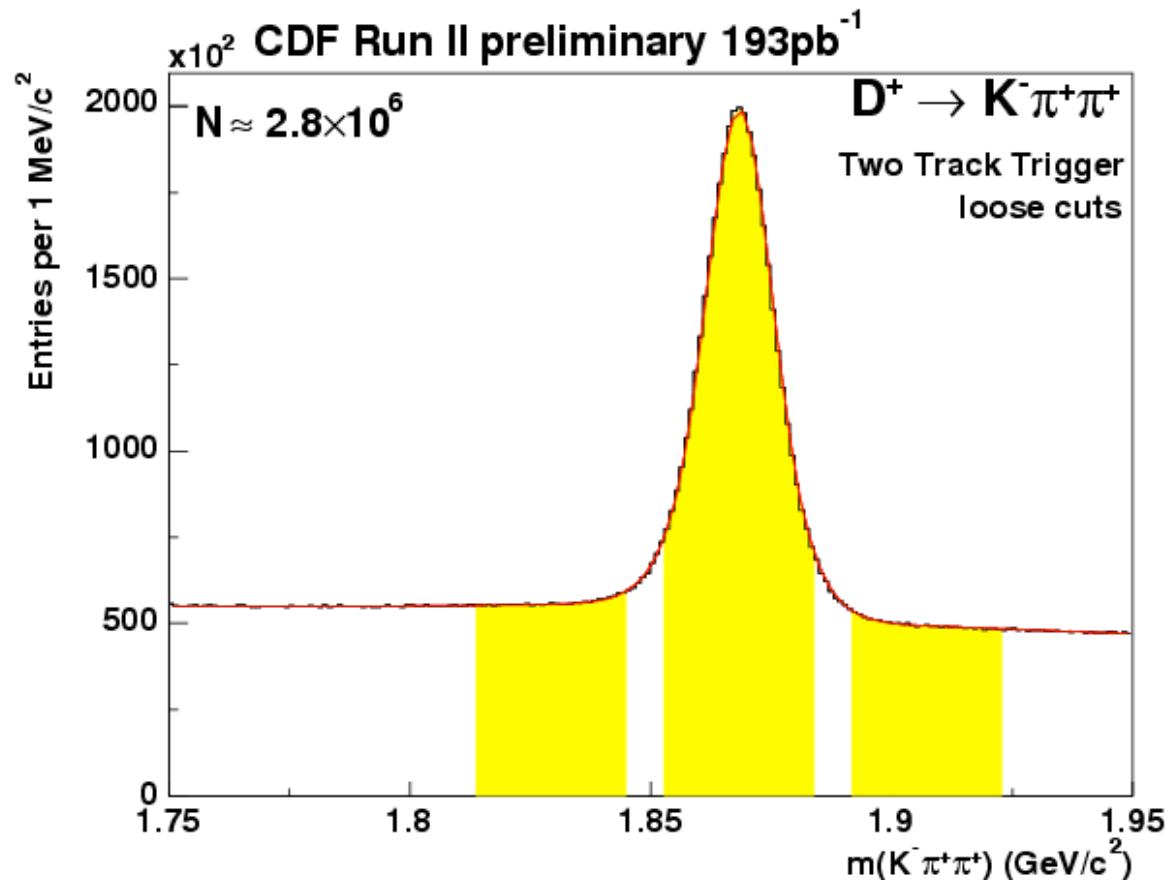
trigger
confirmation

vertex and mass
fit with D^0 to D^*
pointing constraint



$L_{xy}(D^0) > 500 \mu\text{m}$

$\pm 3\sigma$ mass window cuts



trigger confirmation

third track

$P_T > 500 \text{ MeV}/c$

vertex $\chi^2 (xy) < 20$

|impact parameter of D^+ |
 $\leq 500 \mu\text{m}$

$m(K^- \pi^+ \pi^+) - m(K^- \pi^+)$
 $\geq 0.18 \text{ MeV}/c^2$

(reject background from partially reconstructed D^{*+})

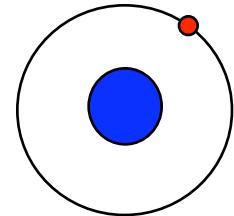
(8/23/2004)

P. Kurchin, Charm Physics @ CDF, DPF@UCR

Mass and Width of the L=1 D Mesons

D mesons ($c\bar{q}$) have radial and angular excited states.

Precision measurements of masses and widths help refine heavy quark effective theory.

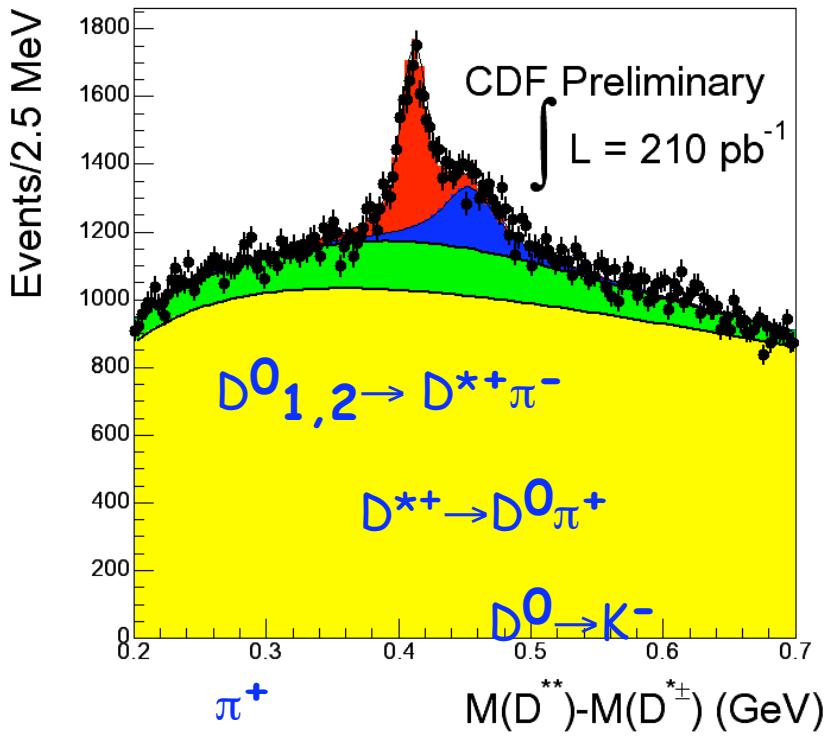


CDF's large sample of D^{*+} and D^+ decays allows study of the "narrow" width $L=1, J=1,2$ states via the decays

$$D_{1,2}^0 \rightarrow D^{*+}\pi^-, D^{*+} \rightarrow D^0\pi^+, D^0 \rightarrow K^-\pi^+ + \text{charge conjugate}$$

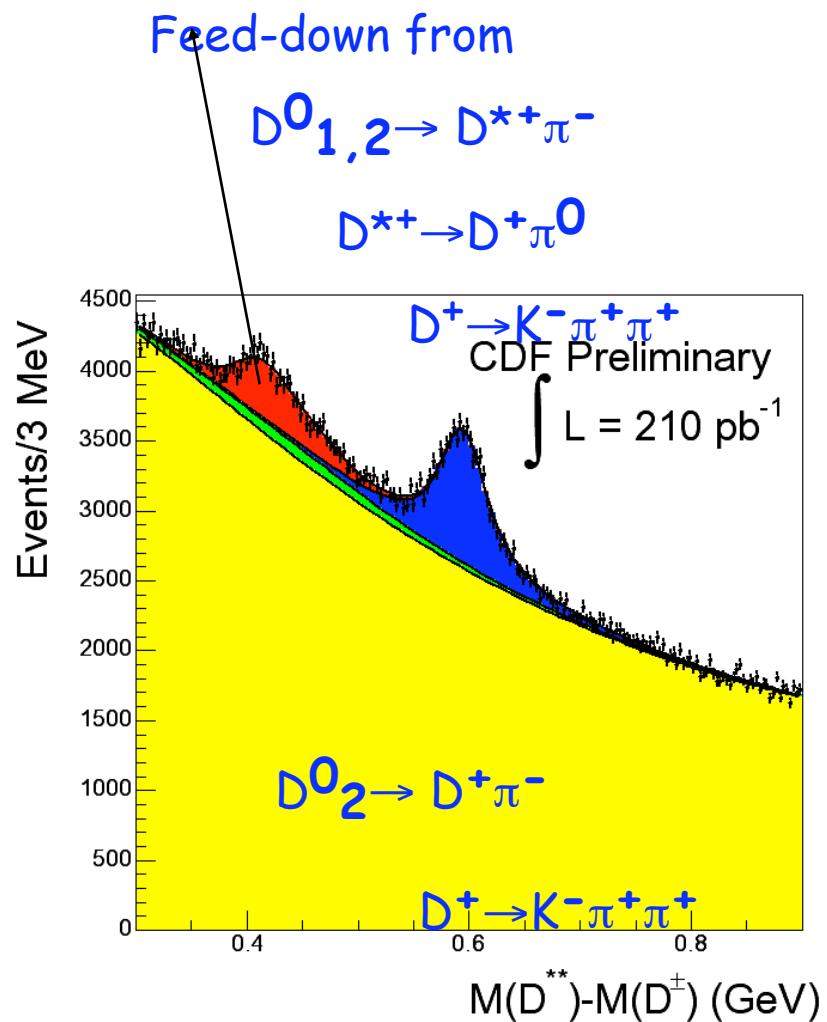
$$D_2^0 \rightarrow D^+\pi^-, D^+ \rightarrow K^+\pi^-\pi^- + \text{charge conjugate}$$

Note that both $D_{1,2}^0$ decay to D^{*+} but only D_2^0 decays to D^+ .



- $D^0_1 \sim 7000$ signal
- $D^0_2 \sim 4000$ signal
- broad $D^0_{1,2}$ background
- combinatoric background

D₁ and D₂ Signals



D^{**} Mass and Width Results

$$M(D^0_1) - M(D^{*+}) = 411.7 \pm 0.7 \pm 0.4 \text{ MeV} \quad M(D^0_2) - M(D^{*+}) = 594.0 \pm 0.6 \pm 0.5 \text{ MeV}$$

$$M(D^0_1) = 2421.7 \pm 0.7 \pm 0.6 \text{ MeV}$$

$$M(D^0_2) = 2463.3 \pm 0.6 \pm 0.8 \text{ MeV}$$

$$\Gamma(D^0_1) = 20.0 \pm 1.7 \pm 1.3 \text{ MeV}$$

$$\Gamma(D^0_2) = 49.2 \pm 2.1 \pm 1.2 \text{ MeV}$$

Source	ΔM_1 (MeV)	$\Delta \Gamma_1$ (MeV)	ΔM_2 (MeV)	$\Delta \Gamma_2$ (MeV)
MC statistics	0.3	1.2	0.4	1.2
BS mass width	0.1	0.4	0.1	0.5
COT corr	0.1	0.0	0.1	0.0
Tracking/B field	0.1	0.2	0.1	0.2
PDG masses	0.5	-	0.5	-
Total for mass	0.6	1.3	0.8	1.3
Total for diff	0.4	1.3	0.5	1.3
Helicity	0.1	0.9	0.1	3.3

CDF D^{**} Mass and Width Results Compared with Other Experiments

	M ₁ (MeV)	Γ ₁ (MeV)	M ₂ (Mev)	Γ ₂ (MeV)
PDG 04	2422 ± 1.8	18.9 +4.6 -3.5	2458.9 ± 2.0	23 ± 5
Belle 03	2421.4 ± 1.5 ± 0.9	23.7 ± 2.7 ± 4.0	2461.6 ± 3.9	45.6 ± 8.0
FOCUS 04			2464.5 ± 1.1 ± 1.9	38.7 ± 5.3 ± 2.9
CDF 04	2421.7 ± 0.7 ± 0.6	20.0 ± 1.7 ± 1.3	2463.3 ± 0.6 ± 0.8	49.2 ± 2.1 ± 1.2

Relative Branching Fraction and Search for Direct CP Asymmetry in $D^0 \rightarrow K^+K^-$ and $\pi^+\pi^-$ decays

$$A_{CP} \equiv \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\overline{D^0} \rightarrow f)}{\Gamma(D^0 \rightarrow f) + \Gamma(\overline{D^0} \rightarrow f)}$$

These Cabibbo-suppressed decays may exhibit direct CP asymmetry due to interference between tree and penguin amplitudes.

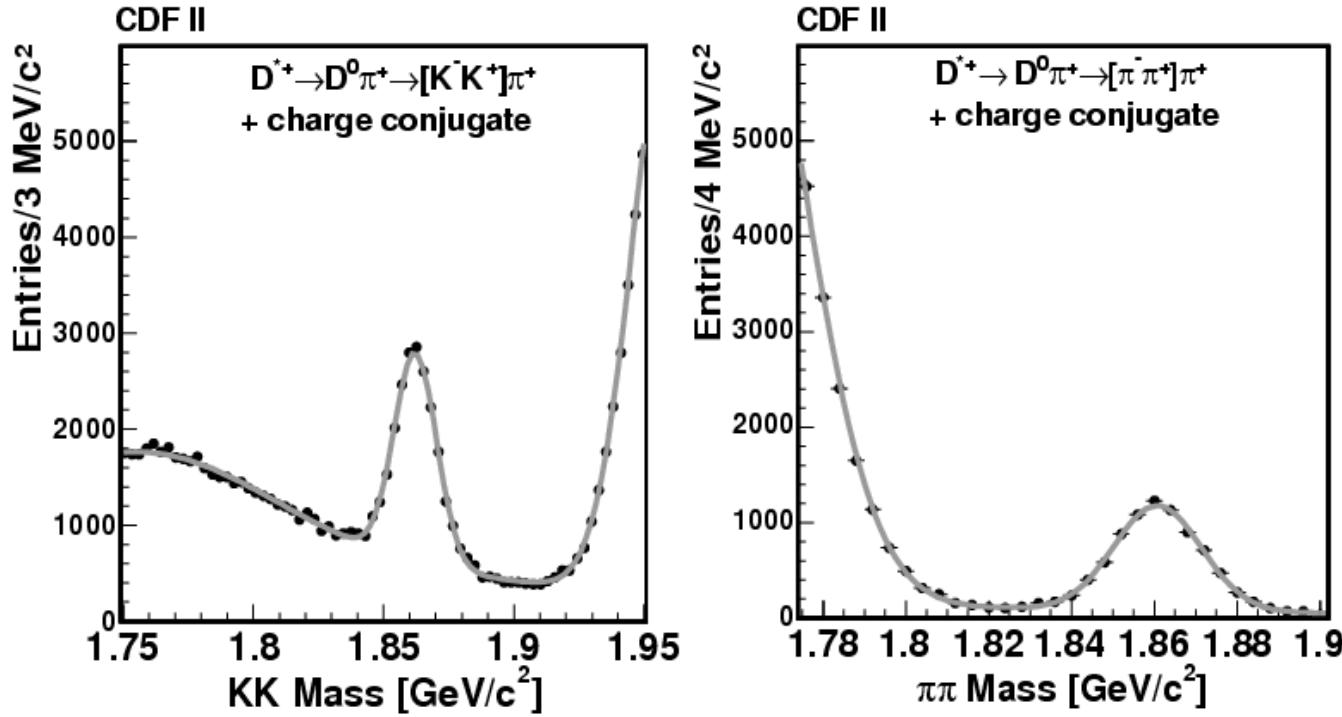
In the standard model, $A_{CP} < 10^{-3}$ and depends on the strong interaction phase difference between the tree and penguin amplitudes.

New physics could produce $A_{CP} \sim O(10^{-2})$.

Precision measurement of the relative branching fraction

$$\frac{\Gamma(D^0 \rightarrow K^+K^-)}{\Gamma(D^0 \rightarrow \pi^+\pi^-)}$$

helps refine theoretical models for final state strong interactions and hence improves the predictive power for A_{CP} .



Suppress D^0 from B with impact parameter cut: $d\mathcal{O}(D^0) < 100 \mu\text{m}$

Mode	D^0	\bar{D}^0	Total
$K\pi$	88310 ± 330	92600 ± 340	180910 ± 480
KK	8190 ± 140	8030 ± 140	16220 ± 200
$\pi\pi$	3660 ± 69	3674 ± 68	7334 ± 97

Determination of Relative Decay Rates

$$\frac{\Gamma(D^0 \rightarrow h^- h^+)}{\Gamma(D^0 \rightarrow K^- \pi^+)} = \frac{N_{h^- h^+}}{N_{K\pi}} \cdot \frac{\epsilon_{K\pi}}{\epsilon_{h^- h^+}}$$

$$\varepsilon(K\pi) / \varepsilon(KK) = 1.1073 \pm 0.0074$$

$$\varepsilon(K\pi) / \varepsilon(\pi\pi) = 0.8867 \pm 0.0056$$

$$\varepsilon(\pi\pi) / \varepsilon(KK) = 1.2488 \pm 0.0078$$

	KK/K π [%]	$\pi\pi/K\pi$ [%]	KK/ $\pi\pi$ [%]
Fit Model	0.64	0.54	0.67
MC Statistic	0.67	0.63	0.62
Trigger simulation	0.34	0.31	0.37
Beam spot size	0.35	0.24	0.35
Material in GEANT	0.28	0.30	0.59
Lifetime difference	0.55	0.55	
D* input spectrum	0.05	<0.01	<0.01
B \rightarrow D* component	0.16	0.08	0.24
Total	1.2	1.1	1.2

Results on Relative Decay Rates (submitted to PRL)

$$\begin{aligned}\Gamma(D^0 \rightarrow KK) / \Gamma(D^0 \rightarrow K\pi) &= 9.92 \pm 0.11(\text{stat}) \pm 0.12(\text{syst}) \% \\ \Gamma(D^0 \rightarrow \pi\pi) / \Gamma(D^0 \rightarrow K\pi) &= 3.594 \pm 0.054(\text{stat}) \pm 0.040(\text{syst}) \% \\ \Gamma(D^0 \rightarrow KK) / \Gamma(D^0 \rightarrow \pi\pi) &= 2.760 \pm 0.040(\text{stat}) \pm 0.034(\text{syst})\end{aligned}$$

Compare with best (non CDF) measurement:

$KK/K\pi$: $9.93 \pm 0.14 \pm 0.14$ % (FOCUS 2003)

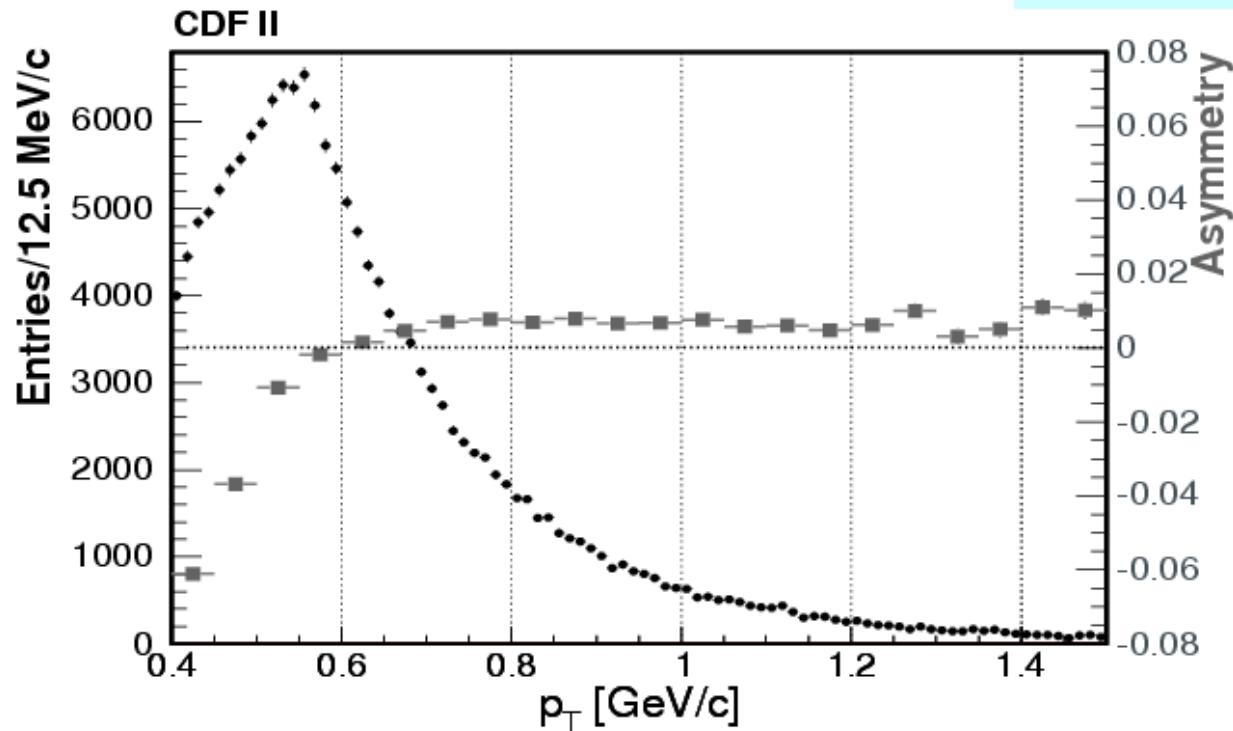
$\pi\pi/K\pi$: $3.53 \pm 0.12 \pm 0.06$ % (FOCUS 2003)

$KK/\pi\pi$: $2.81 \pm 0.10 \pm 0.06$

$$A_{CP} \equiv \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\overline{D^0} \rightarrow f)}{\Gamma(D^0 \rightarrow f) + \Gamma(\overline{D^0} \rightarrow f)}$$



$$A_Q \equiv \frac{N^+ - N^-}{N^+ + N^-}$$



$$A(\text{residual}) = (0.35 \pm 0.53)\%$$

CDF Result Submitted to PRL:

$$A(D^\circ \rightarrow K^+K^-) = 2.0 \pm 1.2(stat) \pm 0.6(syst) \%$$

$$A(D^\circ \rightarrow \pi^+\pi^-) = 1.0 \pm 1.3(stat) \pm 0.6(syst) \%$$

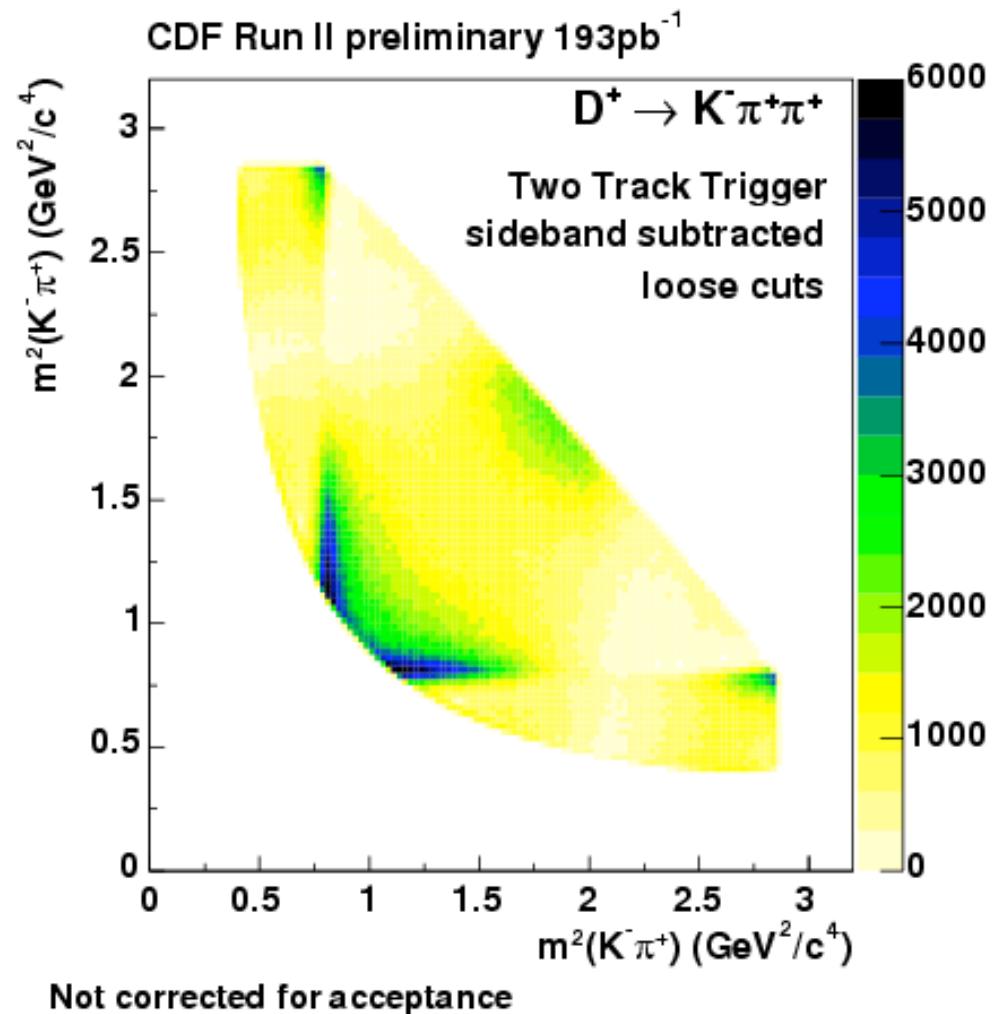
Compare with best (non CDF) measurement:

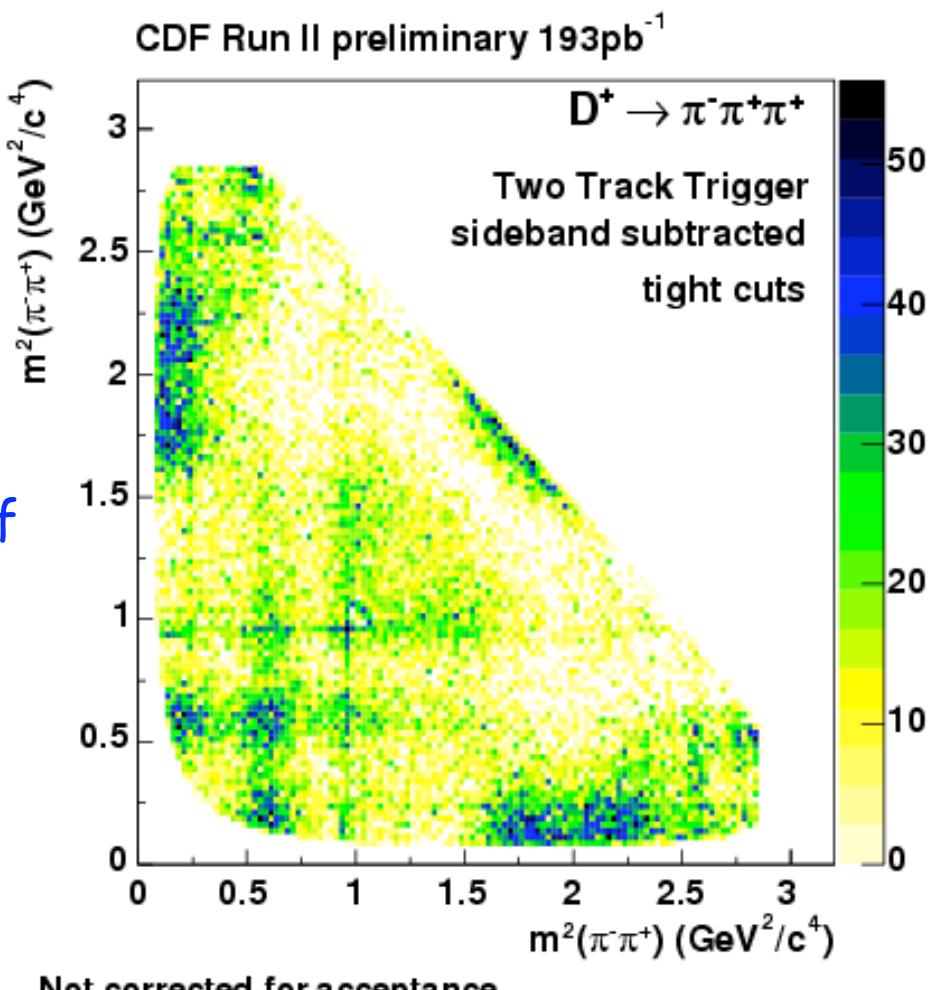
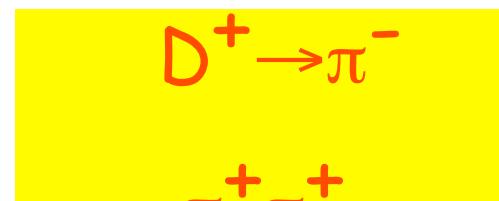
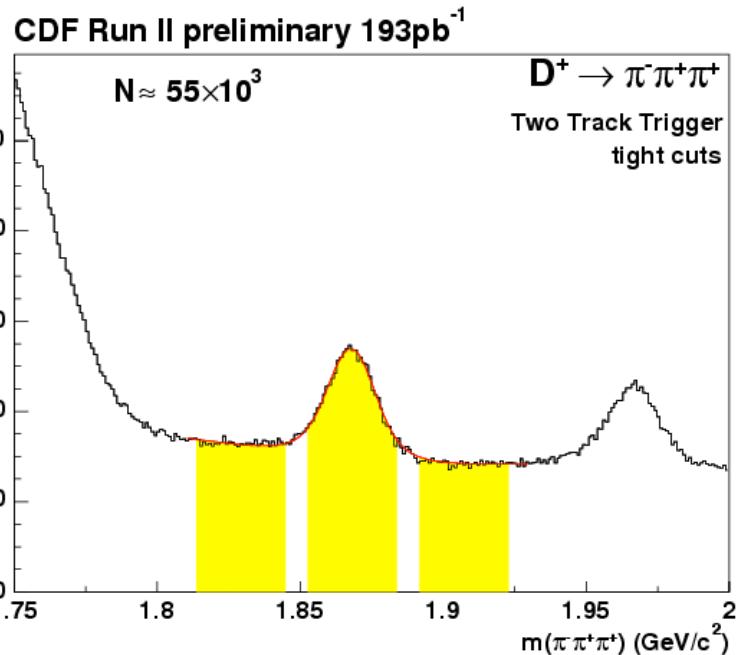
$A_{CP}(KK)$: $0.0 \pm 2.2 \pm 0.8 \%$ (CLEO 2002)

$A_{CP}(\pi\pi)$: $1.9 \pm 3.2 \pm 0.8 \%$ (CLEO 2002)

D⁺ Dalitz Properties

Compare Dalitz
structure of Cabibbo-
favored and Cabibbo-
suppressed decays





We will soon improve knowledge of
 $\text{BR}(D^+ \rightarrow \pi^+ \pi^- \pi^-)$

Theory predicts direct CP
asymmetry could be $O(10^{-3})$

E791: $A = -0.017 \pm 0.042$,
Phys. Lett. B403 (1997)

Summary

Tevatron Collider is a highly productive Charm Factory

Significantly improved measurements of D^{**} Masses and Widths reveal a larger width for the D_2

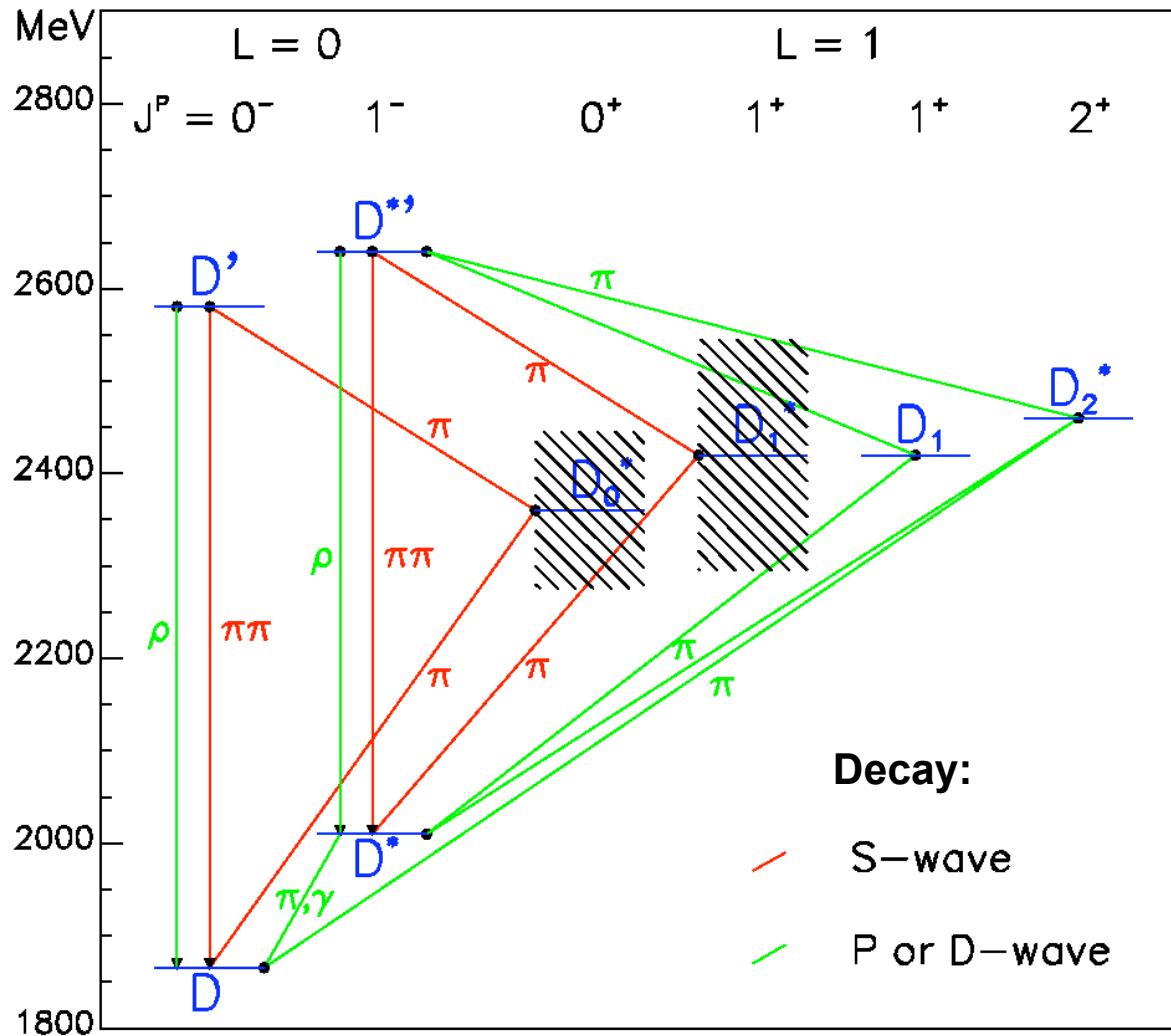
Improved Measurements of Relative Branching Fractions and CP Asymmetries for $D^0 \rightarrow K^+K^-$ and $\pi^+\pi^-$ decays but no asymmetry yet seen

Large statistics Dalitz plot for $D^+ \rightarrow K^-\pi^+\pi^+$ and $\pi^-\pi^+\pi^+$ decays promises improved branching and asymmetry measurements to come

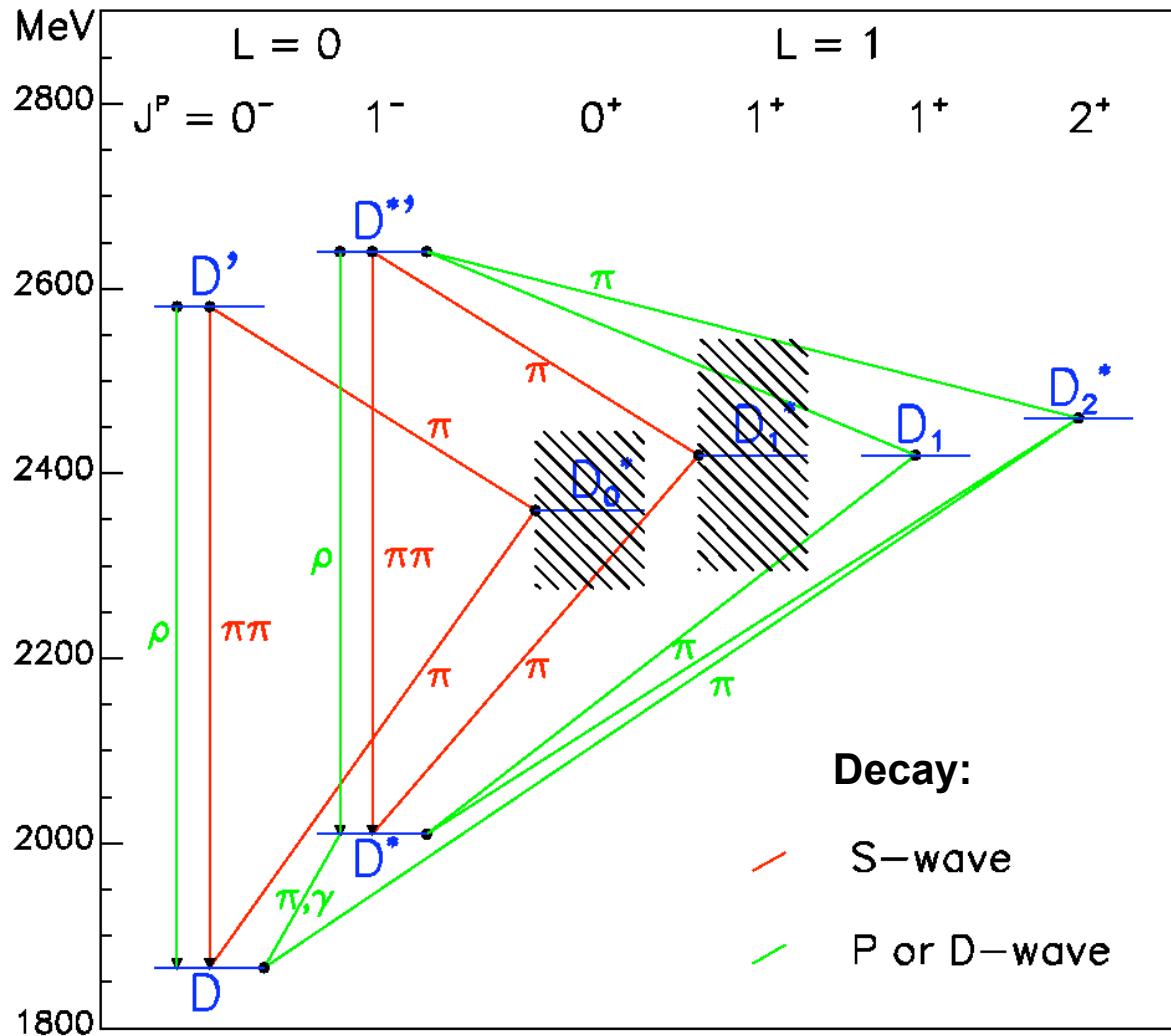
CDF RUN II total yields for charm could be 10X that reported here!

Supplemental Slides

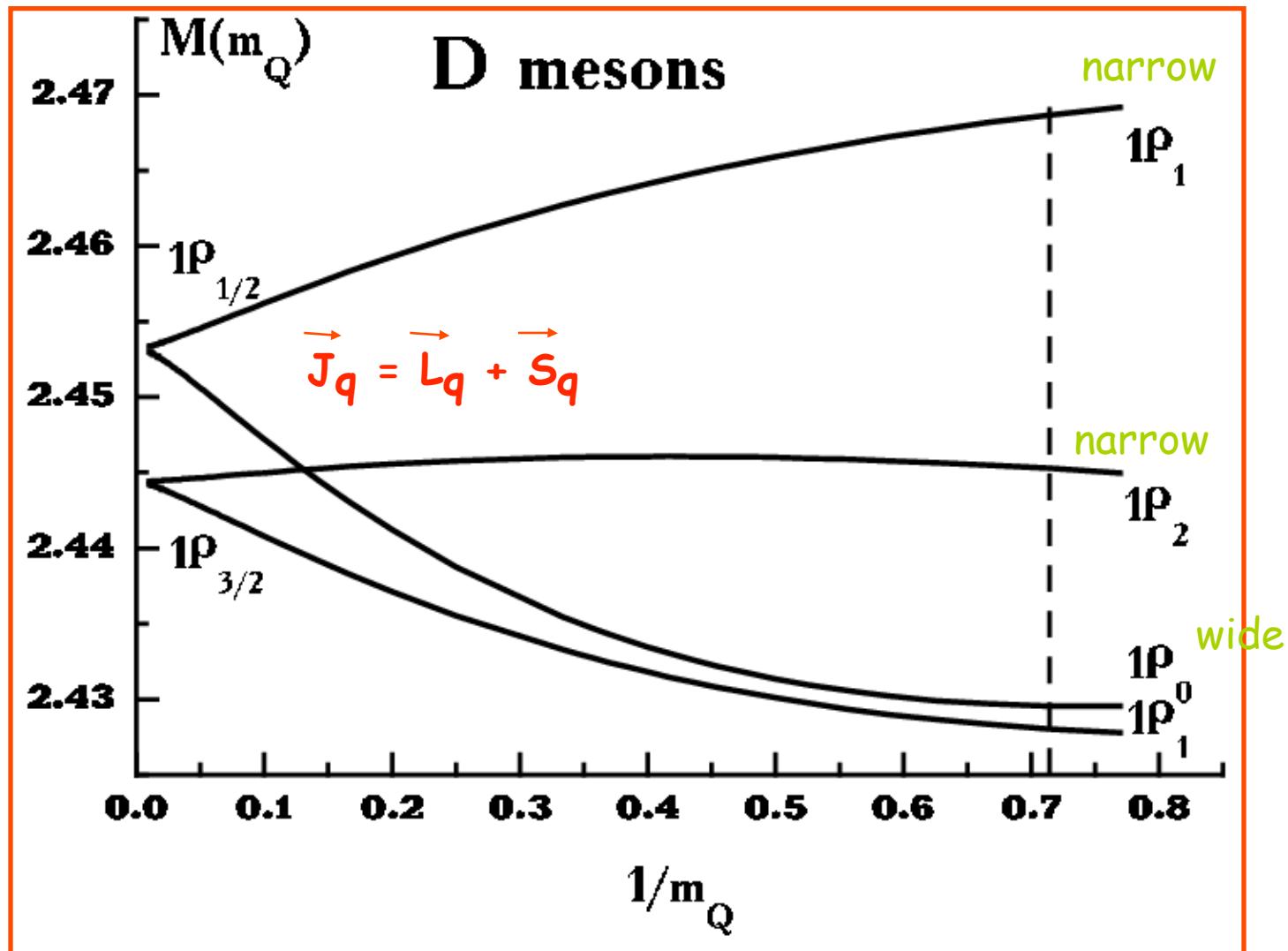
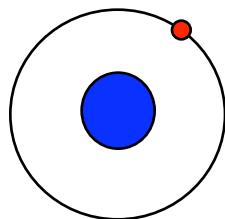
Mass and Width of the L=1 D Mesons



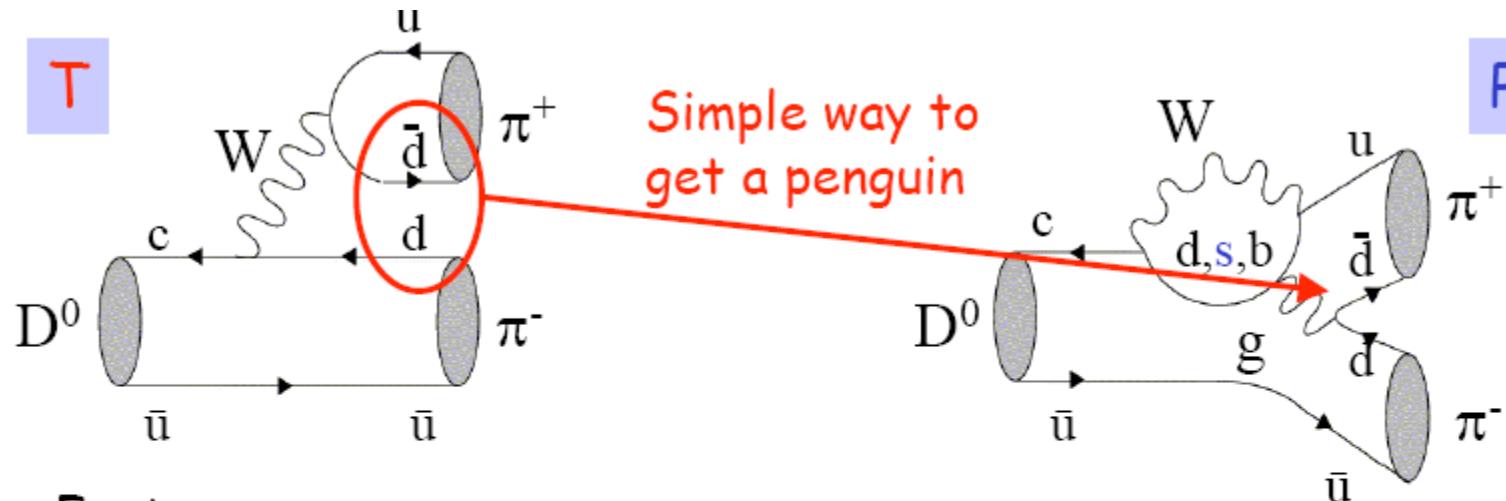
Mass and Width of the L=1 D Mesons



Mass Splitting in Heavy Quark Effective Theory



Direct CP Violation in Cabibbo-Suppressed D0 Decays

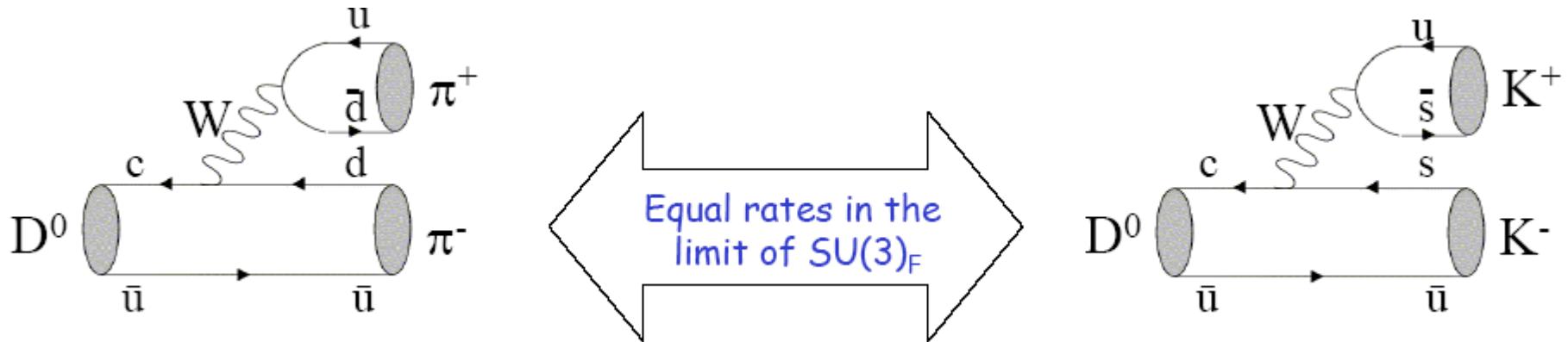


- Features:
 - $V_{cd}^* V_{ud}$ VS $V_{cs}^* V_{us}$ → different weak phases
 - $\Delta I = 1/2, 3/2$ VS $\Delta I = 1/2$ → different strong phases are likely
 - $m_s < m_c$ → long distance effects dominate → FSI
 - Heavy exotic particles can run in the loop → sensitive to NP

$$A_{CP} \approx \frac{\text{Im}(V_{cd}^* V_{ud} V_{cs}^* V_{us})}{\lambda^2} \sin \delta_{st} \frac{P}{T} \approx A^2 \eta \lambda^4 \sin \delta_{st} \frac{P}{T} < 10^{-3}$$

$$A_{CP}^{\text{New Physics}} \sim O(1\%)$$

Relative Branching Ratio and Final State Interactions



- Phase space favors $\pi^+\pi^-$ over K^+K^- , larger form factors and decay constants favors the K^+K^- final state:

$$\left. \frac{\Gamma(D^0 \rightarrow K^- K^+)}{\Gamma(D^0 \rightarrow \pi^- \pi^+)} \right|_{SM} \approx 1.4 \text{ to be compared with } \sim 2.8 \text{ from experiments}$$

- Phenomenological isospin analyses using D^0 and D^+ BR derive magnitudes and phase shifts of the FSI amplitudes:
 - are able to reproduce the experimental $K^+K^-/\pi^+\pi^-$ ratio
 - predict $A_{CP} \sim 10^{-4} \div 10^{-3}$
- High precision measurements of the relative BR improve the predictive power for A_{CP}

CDF D^{**} Mass and Width Results Compared with other expts.

